WBS 1.4 – The Electromagnetic Calorimeter

I. Introduction

A. Brief Description

The electromagnetic calorimeter (EMCAL) consists of 10,100 lead-tungstate (PWO) crystals of identical tapered rectangular shape and the size is 220 mm in length and 28×28 mm^2 in cross section at a larger end and 27.2×27.2 mm^2 at the narrower end. They are wrapped by a Tyvek sheet to improve the collection efficiency of scintillation light. The scintillation light from each of these crystals is detected by a one-inch diameter photomultiplier tube (PMT) of length about 60 mm. These PMT's have 5-6 dynodes, requiring 6-7 high voltages ranging from 200 to 1000 V. We will use a single set of 6-7 HV power supplies to provide these 6-7 different voltages for a group of about 100 PMT's. We will use a ribbon cable and daisy chain groups of PMT's to deliver HV's.

Signal from the PMT's are carried by coaxial cables of 2-4 m in lengths to front-end boards (FEB's) in subracks near the detector. The FEB's consist of multi-range ADC's called QIE9's and supporting electronics to digitize the signal with more than a 10^5 dynamic range.

Since PWO crystals are too fragile and break if they are stack up one on top of another, we will fabricate a square cell structure using aluminum strips, which are span in a strong frame. We will insert a combination of a PWO crystal and a PMT, which are glued together, into its own cell.

An optical fiber carrying light from LED-based light pulser system will be attached to each crystal near the PMT. This will be used to test functionality of the PMT and PWO crystal during installation, and to calibrate their sensitivity after operation starts.

B. Definition of Staged Detector

In order to produce an EMCAL with a sufficient number of PWO crystals to be able to study interesting physics by 2009, we plan to stage the construction of EMCAL. The first-stage EMCAL will have about half of 10,100 crystals. We have more than a year of schedule float (353 days) with this 50% detector. However, this detector will provide about 60% of acceptance for many of interesting physics topics using final states containing π^0 and η. This is accomplished by strategically populating those 50% of the crystals. If everything goes well, many more than 50% of the crystals will ready to be installed in the support structure before the end of 2009 shutdown.

II. Project Flow & Cost

A. The following table lists the dates that major components are ready to be installed, and the dates that they are needed for timely completion of BTeV.

	Ready-by dates	Need-by dates	Floats
Support structure	Dec 27, 2007	Aug 27, 2008	168 days
20% of crystals-PMT's	Dec. 28, 2008	Dec 1, 2008	232 days
50% of crystals-PMT's	April 11, 2008	Sept. 7, 2009	353 days
75% of crystals-PMT's	Nov. 28, 2008	July 1, 2010	397 days
100% of crystals-PMT's	Sept. 24, 2009	Aug. 2, 2010	212 days

B. Description of how project will work

We will start with the front-end chip, QIE, production in FY05 mostly because the 0.8μm technology, which is used in the current design, may be obsolete in the not-so-distant future. We will delay the front-end board design until FY07 since we don't need these boards for a while, and this will match the funding constraints better.

In FY06, we will start Chinese crystal production. Since the Chinese vendor does not have large production capacity (~150 crystals/month), it is beneficial to them and us to produce crystals over longer period. They will be tested by our Chinese colleagues at Nanjing, Shandong and USTC before they are sent to the US. We will measure the light outputs, their uniformity over the lengths of the crystals, and radiation sensitivities. Once the crystals are shipped to the US, we will visually inspect all crystals to make sure they are not cracked or otherwise physically damaged. Sample of crystals will be measured to make sure that they meet our specs, and there in no significant differences between the US and Chinese measurements.

In FY07, we will start Russian crystals. They have so much capacity (1000/months) to produce their share of crystals in 5 months (10 months for all BTeV crystals), but to match the funding profile better, we will acquire ~5000 crystals over two years (230/month). It is likely that before FY07, they are busy with CMS endcap crystals, although CMS may forgo endcap calorimeter, in which case the Russian vendor may be able to produce our crystals earlier. Russian crystals will be tested by our IHEP colleagues, but otherwise treated in a similar fashion as the Chinese crystals.

We will also start PMT production in FY07. Acceptance tests will be done in the US.

Each of the crystals will be glued to a PMT, and tested again using a light pulser to make sure that the glue joint is good. They will be stored until the support structure is ready in the beginning of FY08.

The parts for the mechanical support structure will be acquired in FY07, and will be assembled after the summer 2007 shutdown period when the Assembly Hall in the C0 building has enough space. Before then, the muon toroids occupy the space. The assembly should be finished by Dec 2007.

When the support structure is ready for crystal/PMT loading, we will have over 5000 crystals and PMT's in hand. We estimate that by April 2008, we will have

enough crystals/PMT's glued together and ready for loading to complete the staged EMCAL with ~5000 crystals. As they are loaded into the support structure, they will be tested to make sure they all work.

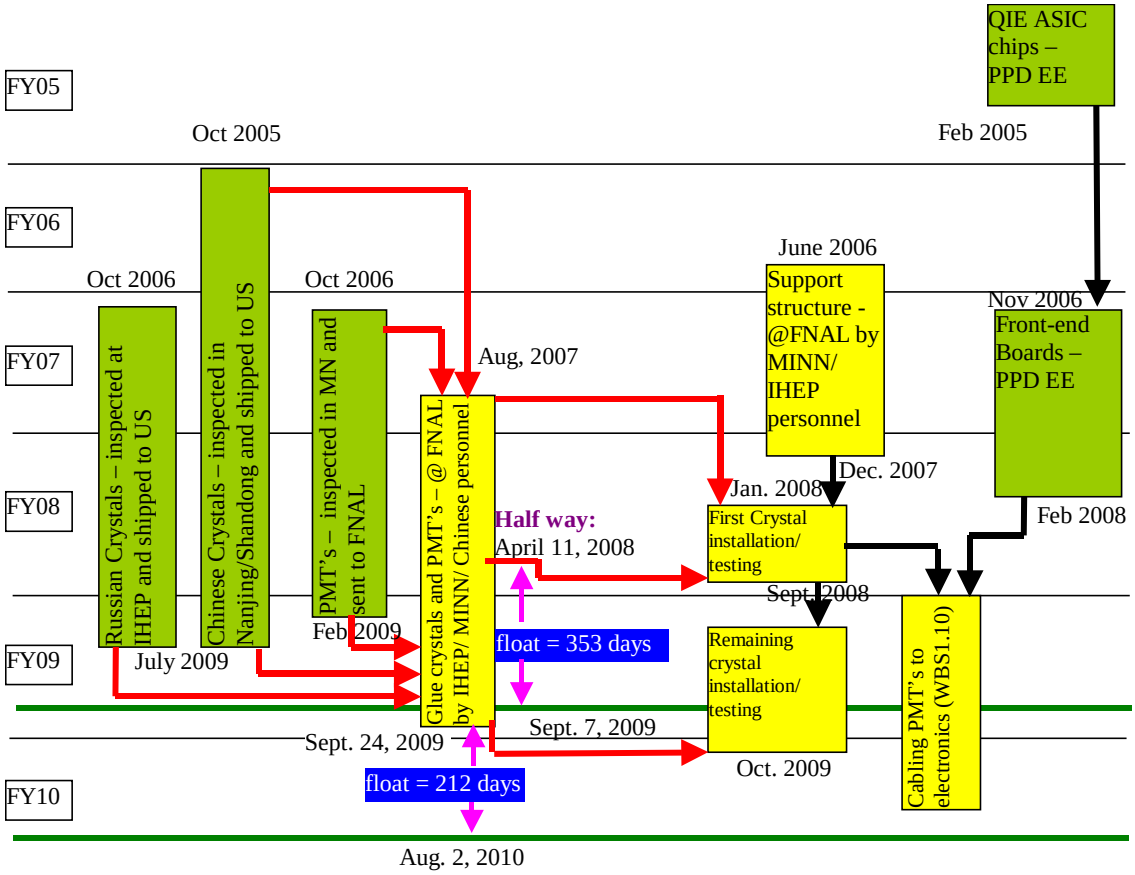


Fig. 1 Project Flow diagram and key dates

If everything goes smoothly, we will load about 1000 crystals/month, and by August 2008, the loading rate is limited by the availability of new crystals and PMT's. Nevertheless, by May of 2009, we should have all the crystals in the support structure before the 2009 summer shutdown when the staged BTeV is put together.

However, the history of crystal calorimeter has its share of crystal production delays. We feel, however, it is very likely that at least half of the crystals will be installed by the summer 2009 since even if the production rate is half as much as projected, this will be accomplished.

Some of the risk factors and our mitigation strategies associated with crystal production delays are discussed near the end of this chapter.

When the FEB boards are fabricated, tested and ready to be installed (February 2008), we will load them in the subracks near the detector, and we will connect signal as well as HV cables to the PMT's, and do more comprehensive tests all the way to the FEB boards.

When a partial DAQ system is available in the fall 2008, we will connect FEB's to the DAQ to carry out whole-system tests.

C. The labor profile is shown below. On the average, we will need about 10 FTE's to do the work. Considering that many of us are multitasking, we will need 15-20 "bodies" as the Lehman CD-1 reviewers pointed out. Concentration of work on EMCAL specific database work in FY06 will be spread over longer time scale.

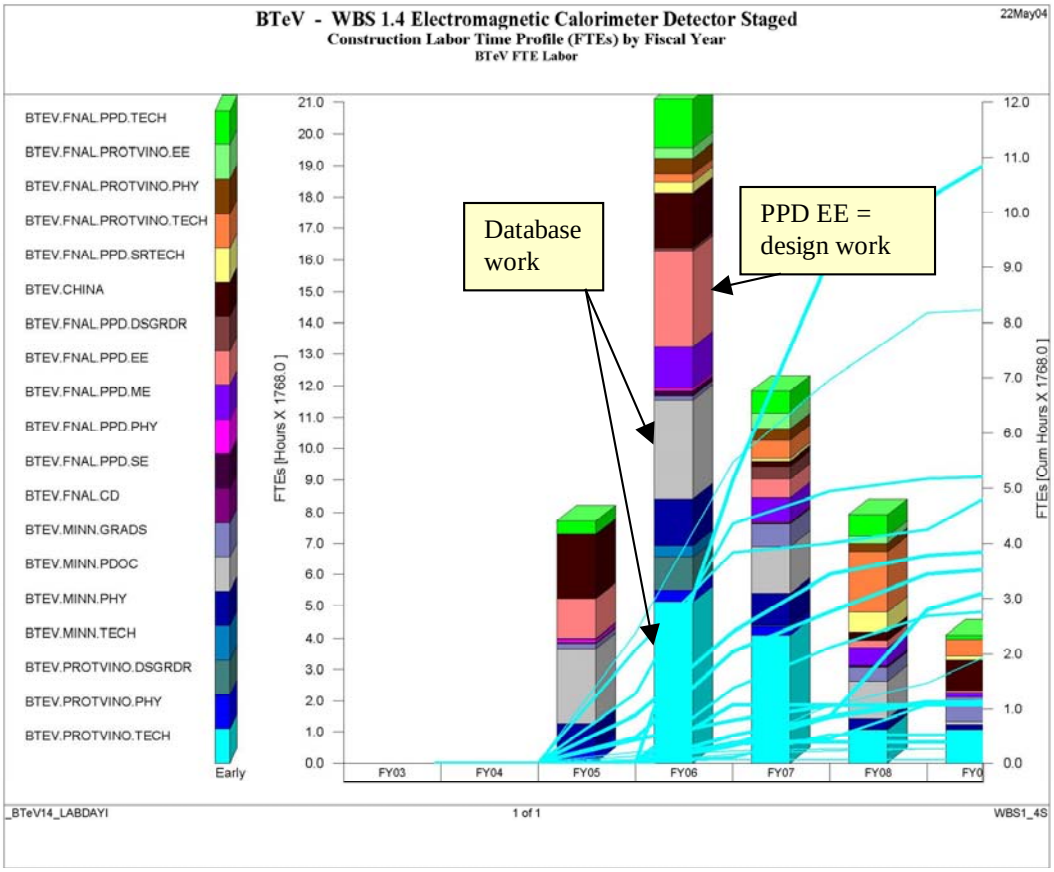
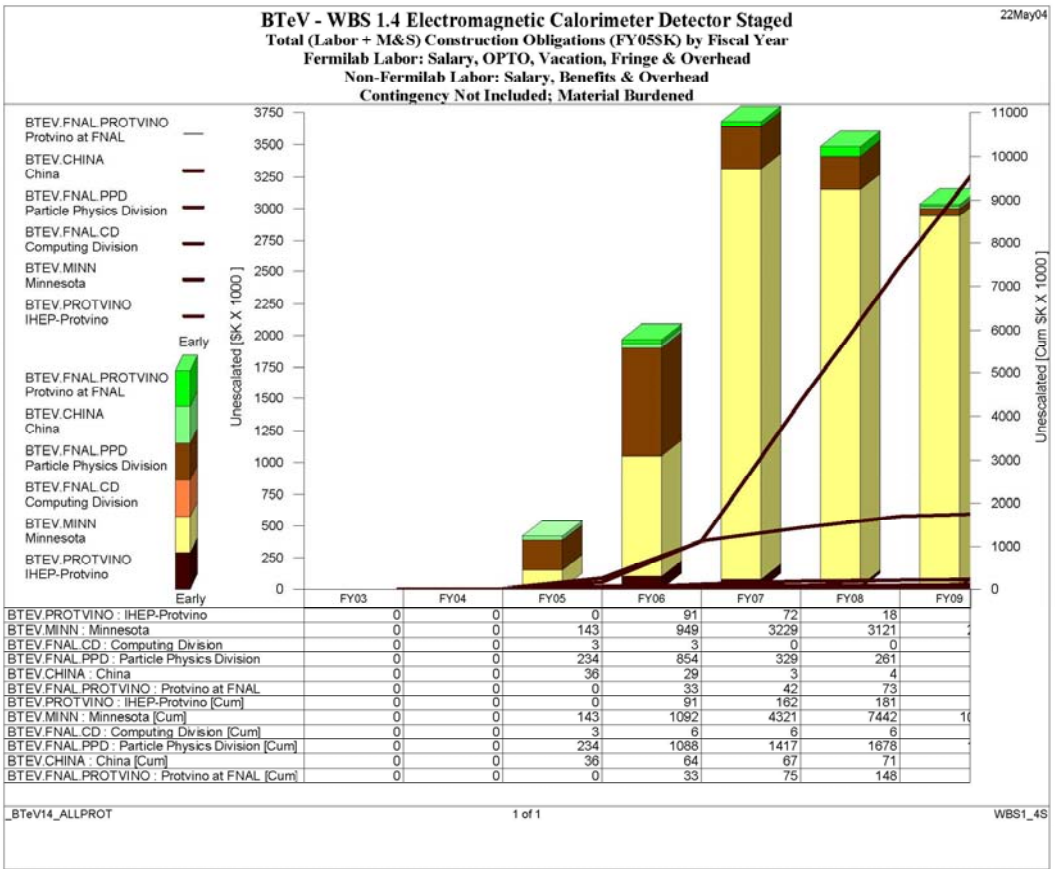


Fig. 2 Labor profile

D. The total base cost of EMCAL is $12.5M and $16.7M including contingencies, with average contingency rate of 33.6%. Only $2M of the base is for labor and the rest (over $10M) is for M&S because PWO crystals and PMT's are expensive. The cost profile by fiscal year is given below. This represents $300k increase to speed up the Chinese crystal production by investing it to boost their production capacity (in the form of higher unit cost).



	FY03	FY04	FY05	FY06	FY07	FY08	FY09
BTEV.PROTVINO : IHEP-Protvino	0	0	0	91	72	18	
BTEV.MINN : Minnesota	0	0	143	949	3229	3121	
BTEV.FNAL.CD : Computing Division	0	0	3	3	0	0	
BTEV.FNAL.PPD : Particle Physics Division	0	0	234	854	329	261	
BTEV.CHINA : China	0	0	36	29	3	4	
BTEV.FNAL.PROTVINO : Protvino at FNAL	0	0	0	33	42	73	
BTEV.PROTVINO : IHEP-Protvino [Cum]	0	0	0	91	162	181	
BTEV.MINN : Minnesota [Cum]	0	0	143	1092	4321	7442	
BTEV.FNAL.CD : Computing Division [Cum]	0	0	3	6	6	6	
BTEV.FNAL.PPD : Particle Physics Division [Cum]	0	0	234	1088	1417	1678	
BTEV.CHINA : China [Cum]	0	0	36	64	67	71	
BTEV.FNAL.PROTVINO : Protvino at FNAL [Cum]	0	0	0	33	75	148	

Fig. 3 Cost Profile

E. Critical path

a. As shown in Fig. 1, the critical path is for a chain of events including crystals production and gluing of PMT's to the crystals. For the stage 1 completion, the last of the required 5000 crystals with PMT's glued to them will be ready for insertion (April 2008) 353 days in advance of so-called "need by date of Sept. 2009.

b. The support structure will be ready for loading in December 2007, when more than 5000 crystals should be in hand.

c. Loading of crystals for the full completion has 168 days of floats. We can increase this by running two shift/day and two crews/shift.

d. If everything goes smoothly, we will have all the crystals in hand by the first shutdown (2009).

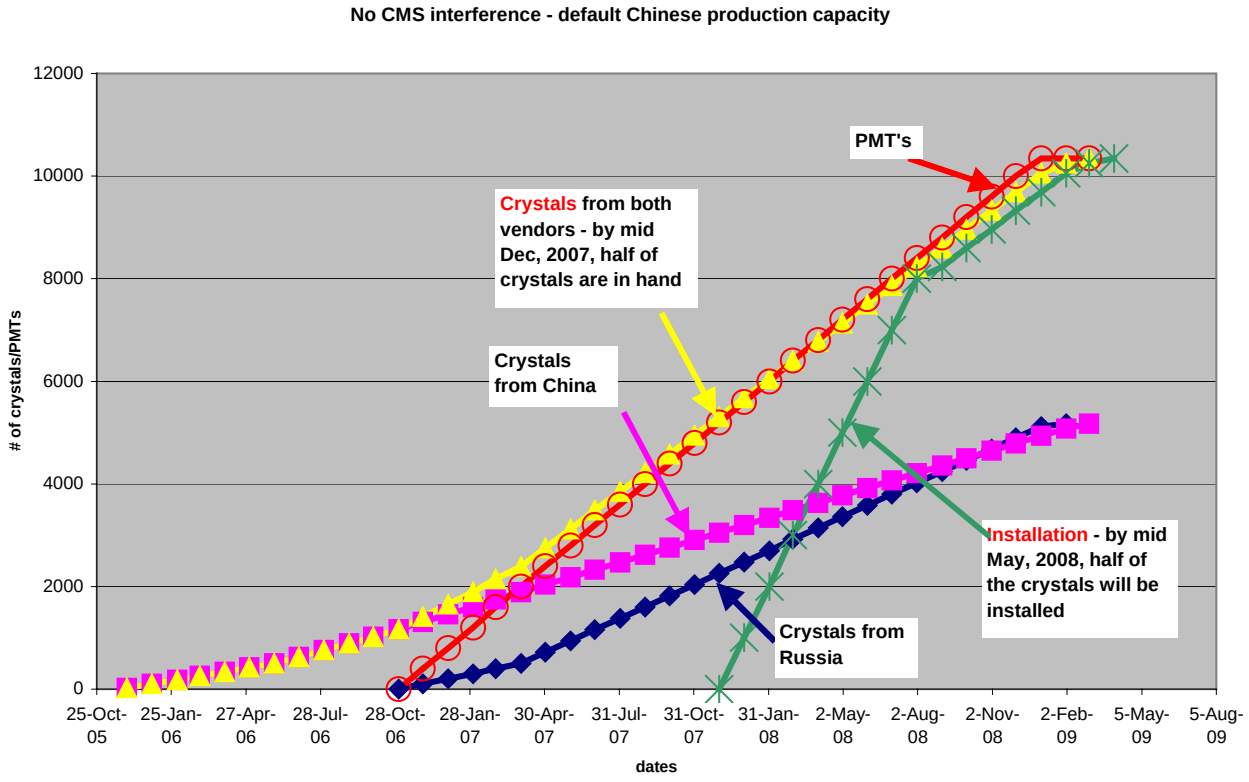


Fig. 4 Schedule of crystal and PMT acquisition and their installation

F. OBrowser views of Costs

Activity ID	Activity Name	Material($)	Labor($)	Base Cost($)	Material Contingency(%)	Labor Contingency(%)	Total FY05	Total FY06	Total FY07	Total FY08	Total FY09	Total FY05-09
1.4.1	Detector - PWO Crystals	6,093,310	93,752	6,187,062	40	30	55,146	384,831	1,153,295	2,933,106	0	4,526,378
1.4.2	Detectors - PMT's bases	2,149,969	141,332	2,291,301	28	24	2,525	203,353	1,337,638	1,358,152	0	2,901,668
1.4.3	EMCAL Electronics and Associated Infrastructure	1,510,739	639,067	2,149,806	30	30	387,907	469,960	1,925,088	10,111	0	2,793,065
1.4.4	Mech Air and Temperature ctrl Systems	402,561	600,452	1,003,013	20	24	0	654,561	227,616	291,286	0	1,173,463
1.4.5	Integration and Testing	114,542	460,324	574,866	26	32	4,376	662,986	76,653	8,933	0	752,946
1.4.6	EM Calorimeter Detector Subproject Management	67,975	191,024	258,999	38	25	43,353	77,248	73,697	107,282	0	301,581
1.4	**Subproject 1.4**	**10,339,095**	**2,125,951**	**12,465,046**	**35**	**28**	**493,307**	**2,452,939**	**4,793,987**	**4,708,869**	**0**	**12,449,101**

G. How costs have changed from CD-1 review: By making activities run in parallel, we were able to spread the purchasing of crystals and PMT's over longer term and were able to delay spending of money to later years. For example, we should be able to start testing crystals earlier for each OpenPlan activity of purchase, which consists of multiple physical batches of crystal shipments. As soon as the first shipment arrives, the testing can start. The following graph shows how the cost profile for EMCAL changed since CD-1 review in April 2004.

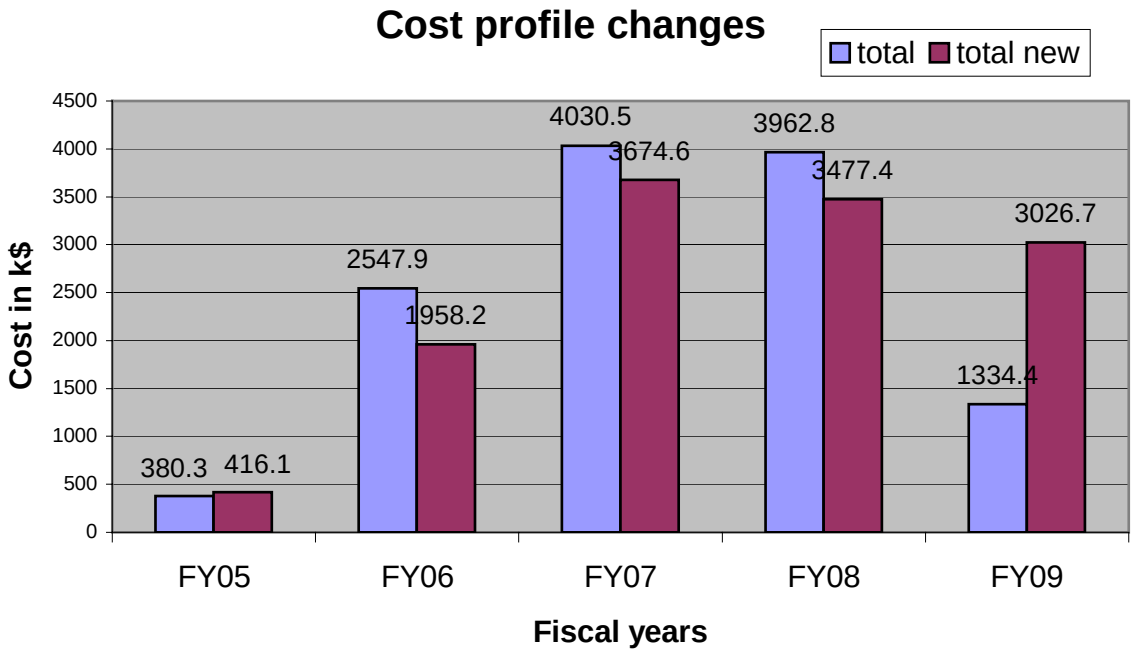


Fig. 5 Cost changes from CD-1

H. Installation

a. Brief description

i. During the shutdown period in 2009, we will move the support structure, with crystals partially loaded and tested, from the Assembly Hall to C0.

ii. Install light pulsers and front-end electronics (FEB) near the detector.

iii. Load crystals (PMT's attached)

iv. Install optical fibers, signal cables and HV cables, and connect them to the light pulsers and front-end electronics (FEB) near the detector, and HV power supplies just outside the C0 Hall.

v. Connect FEB's to DAQ.

vi. During the 2010 shutdown, we will install and test the remaining crystals into the support structure in the C0 Hall. Connect them to FEB, HV power supplies and light pulsers.

b. Time & Effort

We project that it will take about 40 days of work in each of the two shutdown periods. The labor resources we need are 5.5 FTE's, which include physicists (4 FTE's), engineers (EE+ME<0.5 FTE) and technicians (1 FTE).

In case the crystal loading before the shutdown is behind schedule and more needs to be done during the shutdown periods, we will use more crews for crystal loading and/or more than one shift per day to make sure they are done within the allotted time scale.

c. Possible interferences

Since major part of the EMCAL installation operation is the installation of crystals, which takes place between EMCAL and the muon toroids, we do not anticipate any interference with other detector groups.

There will be interference when the support structure is moved into the C0 Hall ((i) above) and when cables are laid out ((ii) above).

III. Response to all CD-1 recommendations

A. Explore ways to arrive at a schedule with comfortable float (>6 months) by working with BTeV Management and Installation & Integration group.

Staged installation of EMCAL is our answer to this recommendation. We now have a minimum of 169 business days (> 6 months) of floats.

B. Add an Installation Engineer to the project.

More engineering is being added as a shared resource to the Project Office.

C. Add US collaborators

We are working on various possibilities.

IV. Give Risk Table & Mitigation Strategies:

As the CMS experiences indicate, acquisition of crystals with only a few manufacturers can be risky. CMS narrowed the vendor field to one fairly early in their process, which may be one of the reasons that they are having trouble with the vendor. We are determined to keep at least two vendors competing for our orders.

Another risk regarding crystal acquisition is that CMS may decide to use SIC as well as Bogoroditsk for their crystal production. In this scenario, both manufacturers will be busy with CMS crystal productions until mid-2007. However, SIC will have 3 times

the current production capacity (or 330 crystals/month) if this happens because CMS needs this capacity. Bogoroditsk currently have enough capacity to produce all 5000 crystals in 5 months. As the schedule diagram below shows, we will be able to finish our crystal production and installation in time.

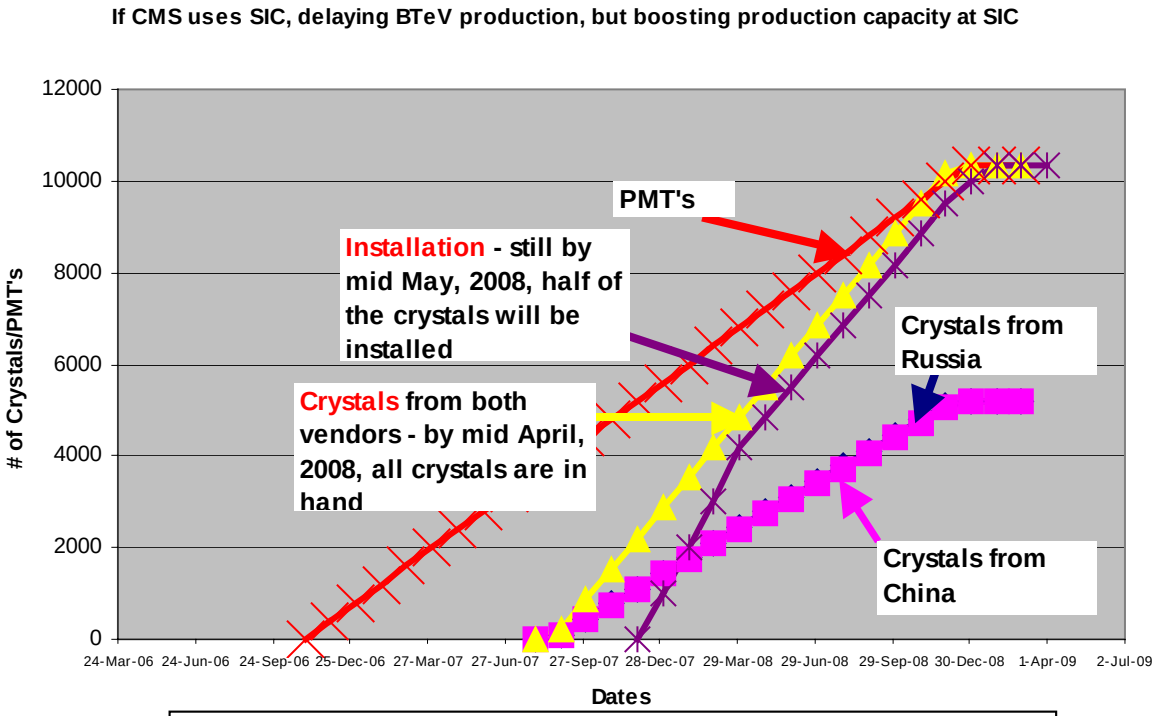


Fig. 6: alternative crystal production schedule in case vendors are busy with CMS crystal production until mid-2007.